

AD-A124 773 A DETERMINATION OF THE MINIMUM FREQUENCY REQUIREMENTS
FOR A PATRIOT BATTN. (U) AIR FORCE INST OF TECH
WRIGHT-PATTERSON AFB OH SCHOOL OF ENGI.. G H SWANSON
UNCLASSIFIED DEC 82 AFIT/GCS/NA/82D-9 F/G 1772:

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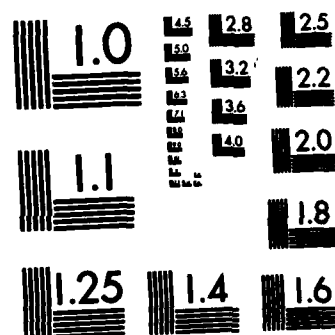
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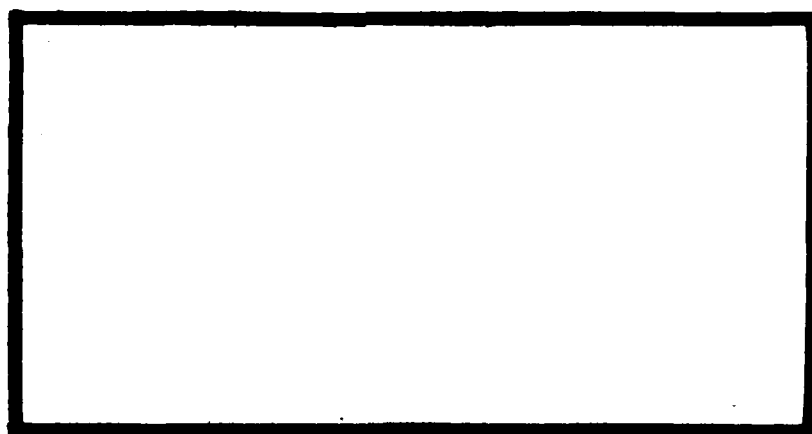
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A DETERMINATION
OF THE MINIMUM FREQUENCY REQUIREMENTS
FOR A PATRIOT BATTALION
UHF COMMUNICATION SYSTEM

THESIS

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OF THE MINIMUM FREQUENCY REQUIREMENTS
FOR A PATRIOT BATTALION UHF COMMUNICATION SYSTEM

THESIS

Presented to the Faculty of the School of Engineering
of the Air Force Institute of Technology
In Partial Fulfillment of the
Requirements for the Degree of
Master of Science

by

Gregory H. Swanson
Captain USA

Graduate Computer Science

December 1982

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PREFACE

This research was performed to provide a quantitative estimate of the minimum frequency requirements for a PATRIOT battalion UHF communication system. To the extent specified by the stated assumptions and constraints, a determination is available from the simulation model described in this thesis.

Thanks are due to Captain Roie Black of the Math Department, Air Force Institute of Technology, for his continuing interest in this thesis and for his many useful suggestions which properly defined the scope of this research. Mr. George Foust of Cas Inc. was extremely helpful in curve-fitting antenna and receiver rejection patterns and analyzing the results to verify the simulation model. Major Dick Wilbanks and Mr. Gene Ashley of the PATRIOT Project Office were instrumental in gathering the much needed information to begin this research.

A very special thanks goes to my wife, Helen, for her encouragement throughout the life of this project.

Gregory H. Swanson

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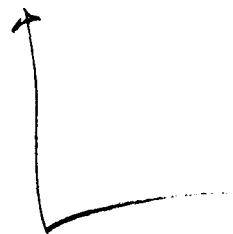
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ABSTRACT

This thesis presents a methodology which simulates the UHF communications network for the Army's PATRIOT battalion. A computer simulation model was developed that reads in coordinates for eleven communicating nodes and their interconnections, and results in the minimum number of frequencies required to support the UHF communications network. Current concepts of PATRIOT battalion employment doctrine determine the frequency requirements obtained. Concepts of antenna rejection at transmitting and receiving nodes, propagation losses, and radio rejection characteristics are incorporated in the model. The model was experimented upon, using deployments currently accepted within the Air Defense Community, and the results of the model are analyzed in this report.



A DETERMINATION
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I. INTRODUCTION

PATRIOT is an air defense guided missile system designed to replace both Nike Hercules and Improved HAWK (I-HAWK) in the field armies. The PATRIOT air defense system is composed of individual battalions each consisting of headquarters and firing elements. The future PATRIOT battalion may consist of eleven such elements with UHF links being the main communications medium between these elements.

Traditional frequency assignment methodology, most notably the ABM plan (Ref. 8:2-27), requires unique frequencies be assigned to each communications link in a network. Thus a very large number of frequencies are required to support a communications network. Since each of the eleven PATRIOT battalion elements will communicate with up to three or four other elements simultaneously, assigning unique frequencies to each link within the PATRIOT battalion is unacceptable and a determination of the number of frequencies actually required to support the PATRIOT battalion is necessary.

This thesis is a modeling effort to determine the minimum frequency requirements for a PATRIOT battalion UHF communication system. The research reported herein involves

the development of a computer model which reads in a set of coordinates of up to eleven communicating nodes and their interconnections, calculates antenna rejection losses at transmitting and receiving nodes, calculates propagation losses and radio off-frequency rejection at receiving nodes, assigns UHF frequencies to the communications network, and double-checks and outputs the battalion frequency requirements.

To simulate the PATRIOT battalion UHF communications network, an eleven node network is used. Six engagement control stations (ECS) and one information and coordination central (ICC) intercommunicate to exchange command and status information. Four communication relay sets (CRS) are used to retransmit radio transmissions, impaired due to terrain or distance factors. The effect of adjacent battalions is not simulated. The simulation model can later be expanded to include all nodes within a specified envelope, constrained by specific antenna and propagation loss characteristics, or unique groups of frequencies can be used at each battalion and repeated at distant battalions based upon the propagation loss characteristics.

The frequency assignment methodology used in this report is a preliminary accomplishment of this model and was required since traditional frequency assignment algorithms are not efficient in that they require unique frequencies for each link. The frequency assignment methodology

developed in this report will allow initial frequency assignments to be performed based upon the co-site mutual interference requirements alone (Ref. 8:2-20 - 2-33).

The Problem Statement

The primary problem addressed in this effort is that very little quantitative frequency assignment planning for the PATRIOT battalion UHF communication network has been performed. The limited extent to which this topic has been previously studied was verified by a rather thorough literature search of documents held by both the PATRIOT Project Office and CAS Inc.

Current frequency assignment methods such as the ABM plan are in the process of automation (Ref. 9:5-1 - 5-20). However, these methods require large numbers of frequencies when a limited number of frequencies are available (Ref. 10:1). Such methods are unacceptable to PATRIOT since they do not provide for the complex interconnections used with PATRIOT (Ref. 4:1-4). Although the PATRIOT Air Defense System utilizes the Army's standard UHF radio, the AN/GRC-103 Radio Set, the method of communication equipment configuration is unique. Three radio sets are integrated into the ICC and ECS shelters while four radio sets are integrated into the CRS shelters. One Antenna Mast Set (AMS) is used to support all antennas required at a node.

Figure 1 illustrates a problem ABM methodology would

have with a frequent occurrence within a PATRIOT battalion.

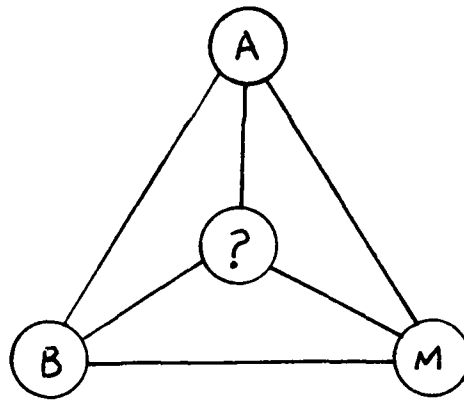


Figure 1. An ABM Assignment Problem

Using the ABM plan, the symbols A, B, and M are assigned to each radio station in a communications network to identify frequencies which may be used by a station. No radio station can be connected to another station assigned the same letter code. In Figure 1, it would not be possible to assign a frequency to the middle station using such methodology.

Goals

Several goals were set at the outset of this work in order to properly measure the degree to which the thesis' overall objective was being met, that objective being to develop a method to answer "what is the minimum number of frequencies required to support a PATRIOT battalion UHF communication system?". These goals were:

1. Construct a computer model to simulate the PATRIOT battalion UHF communication network.
2. Test the model to insure it behaves properly by applying both internal and external verification procedures.
3. Construct a more efficient frequency assignment algorithm than those currently available.
4. Draw general conclusions about the minimum UHF frequency assignment requirements based upon the model's output.

Importance of This Study

There are several reasons why this problem is being studied in addition to the purely academic goal of gaining a better understanding of what computer simulation is all about. Foremost, this is a topic of current Army interest (Ref. 4:1). The PATRIOT Project Office suggested this topic as a candidate for a thesis study and has actively supported the research. Secondly, by constructing a computer model and then documenting the thought processes used in the model's development, one should obtain a better understanding of the real frequency requirements within a directional communications network and improvements may be incorporated into traditional frequency assignment methodology. Finally, by experimenting with the model using some reasonable deployments, a determination may be made as to UHF frequency

requirements within a PATRIOT battalion and an automated system, based upon this effort, to assist the PATRIOT Air Defense planners, refined and incorporated in the onboard software.

Model Application

If this simulation model succeeds in addressing the relevant issues and interactions within the PATRIOT UHF communications network, it may find broad use in developing frequency assignments requirements in tactical simulation models of a far larger scope. One example of a larger scope model is the Army Tactical Frequency Engineering System (ATFES), Frequency Assignment Capability for the Tactical Systems (FACTS) Program. It is also clear that there is yet much to be accomplished in studying this relatively small facet of the overall automated system issue. Hopefully, this thesis can act as the basis model for any future sophistication that may be desired.

Thesis Overview

Chapter II, Background, puts this thesis in proper perspective by providing a more detailed insight into the problem. Included in this chapter is a description of the ABM frequency assignment plan. Chapter III, The Methodology, explains what events were made a part of the model and the manner in which these events interact. Chapter IV, The

Simulation Model, contains the details of the computer model including a description of the model's logic and mechanics. Chapter V, Sample Results, demonstrates the model's capability by an analysis of the output produced from the consideration of deployments currently accepted within the air defense community. Finally, Chapter VI, Summary, Conclusions, and Recommendations, provides a recap of the main points, draws conclusions based upon the model's performance, and illuminates those shortcomings in the present effort which, if corrected, should produce a better product.

II. BACKGROUND

This chapter is intended to provide the reader with a better perspective of the scope of this problem. It does this by describing some important points made by previous studies of this topic and related issues. Following this is a discussion of the traditional ABM frequency assignment plan. Finally, the PATRIOT UHF communication system, which is modeled in this computer simulation, is described in sufficient detail to acquaint the reader with it's capabilities and concepts of employment.

Previous Studies

Many models have been constructed which have attempted to quantify the performance of the Army's AN/GRC-103 Radio Set. These models have been used to analyze the probability of message transfer for both link-to-link and multi-routed communication systems in benign and ECM environments.

One such model is CASCUM, a communications model developed by CAS Inc. (Ref. 1:15). CASCUM provides for the evaluation of both point-to-point (link-to-link) and netted (multi-routed) communication structures. Input parameters can be effectively utilized to enable CASCUM to portray any specific type of communication system using JTIDS or the AN/GRC-103 family of equipments against any desired threat

level. To date, CASCOM has been used by the PATRIOT Project Office to portray PATRIOT's multi-routed network, I-HAWK's point-to-point network utilizing AN/TRC-145 Radio Terminals, and air defense group communications which involve combinations of point-to-point and multi-routed communication networks (Ref. 2:2-13).

Such models as CASCOM, while very powerful in determining communications performance, are not designed as automated tools to assist the PATRIOT air defense and communications planners. This need has, however, been identified as requiring development (Ref. 7:1-4).

The Frequency Assignment Capability for Tactical Systems (FACTS) is used to make frequency assignments for multi-channel radio networks. The program has been designed to make compatible assignments for the AN/GRC-50 (UHF), AN/GRC-103 (Bands I, III, and IV), AN/GRC-144 (Tropo), and AN/GRC-144 (Microwave) Radio Sets. The required input includes the system terminal locations and the frequency resources of the network. The user assigns a color to each site (red, green, or blue) so that sites that are directly connected will not have the same color. Using automated ABM methodology, FACTS makes unique frequency assignments satisfying the co-site mutual interference requirements (Ref. 9:5-1 - 5-2).

A study by CAS Inc. investigated frequency assignment methodology for use within the PATRIOT battalion.

Traditional frequency assignment methods as well as combinations of methods were analyzed to determine viability. An efficient frequency assignment method, suitable for PATRIOT was not found to be currently available (Ref. 3:3).

The ABM Plan

To ensure a satisfactory radio-relay circuit, operating frequencies in a given area must be chosen so as to avoid mutual interference. At UHF, transmitting frequencies at a station must be well separated from the receiving frequencies to guard against intra- and inter-radio transmitter to receiver interference. The receiving frequencies at a station must also be well separated from each other to guard against receiver-to-receiver interference (Ref. 8:2-22).

The ABM frequency assignment plan divides a broad frequency region (all or a large part of a band allocated), into six frequency blocks of suitable widths, based upon transmitter-to-receiver separation requirements. The symbols A, B, and M are assigned to each radio station to identify the group of frequencies that may be used to transmit at that station and the group that may be used to receive. Consecutive transmitting and receiving frequencies are then selected from the respective groups (Ref. 10:14-25).

While current assignment methods using ABM methodology have worked well for determining UHF frequencies for conventional UHF communication configurations, they are deficient

for use with the PATRIOT UHF communication system since they do not provide for the complex interconnections used with PATRIOT (Ref. 4:3).

The PATRIOT UHF Communication System

The PATRIOT battalion consists of the Bn Hq and Hq Battery, and six ADA Batteries, each of which contains up to eight launching stations. The PATRIOT UHF communications system is composed of an Information and Coordination Central (ICC) located at the battalion headquarters, six Engagement Control Stations (ECS), one with each battery, and a growth potential for four Communication Relay Sets (CRS) deployed to retransmit UHF communication traffic between the ICC and ECS. An Antenna Mast Set (AMS), co-located with each ICC, ECS, and CRS, support the antennas for all UHF communication links (Ref. 5:8-1 - 8-6).

The communications equipment provided in the ICC includes three UHF radio stacks. Each stack consists of an AN/GRC-103 Radio Set, TSEC/KG-27 Electronic Key Generator, TD-660 Voice Multiplexer and TD-1065 High Speed Serial Data Buffer. The ECS also contains three stacks of UHF communications equipment while the CRS contain four stacks.

The main communications medium of the PATRIOT battalion when deployed is the UHF link. The ICC and ECS are all expected to have at least two UHF links operating, each to another shelter. Each link may be either direct or via a

CRS if a suitable line-of-sight path is not available. Since the ICC and ECS each have three UHF radios and the CRS has four, the resultant network may be very complex.

III. THE METHODOLOGY

Simulation Requirements

There are specific basic requirements that the simulation model must perform in order that it become representative of the real world environment. The most important requirement is the proper representation of the PATRIOT battalion's UHF communication network. The desired network algorithm must be one that is conceptually correct for the environment being modeled. For this thesis, the network is specified in terms of grid coordinates to insure it is representative of PATRIOT's current employment doctrine.

Another important modeling requirement is that the communication signal rejection and path loss algorithms must be technically correct. Technical characteristics needed to develop these algorithms were obtained from PATRIOT Project Office files, technical manuals, and from the manufacturer.

The last major requirement is that the frequency assignment algorithm within the model must make maximum use of available frequencies and permit frequency sharing since frequency requirements exceed the number of frequencies available.

Scenario

Each node within the PATRIOT battalion is susceptible

to signal interference. Mutual interference within each node is alleviated by choosing frequency assignment algorithms which insure adequate guard bands between operating frequencies. Inter-nodal interference is calculated from antenna rejection, path loss, and receiver rejection characteristics to determine the degree to which operational frequencies may be shared.

The model begins by calculating and storing all inter-nodal distances. Inter-nodal angles are calculated and converted to azimuths which are used in conjunction with the antenna patterns for the UHF parabolic antenna to determine antenna rejection at both the transmitting and receiving nodes. Path loss calculations are performed to determine additional rejection based upon receive distances to desired and interfering nodes.

Also in this model are frequency assignment algorithms designed to make maximum use of operational frequencies by permitting frequency sharing whenever possible. Frequencies are initially assigned based upon intra-nodal mutual interference requirements alone. The initial assignments are then modified to alleviate any inter-nodal interference. The final frequency assignments are then double-checked and output along with the minimum frequency requirement for the battalion.

FORTRAN 77

The FORTRAN 77 computer language was selected as the language of this computer model to be compatible with other air defense performance models used by the PATRIOT Project Office. The CASCOM model may be modified to incorporate this computer model to provide a basis for an automated system to assist the PATRIOT air defense and communications planners. The FACTS program may also be modified to permit the employment of frequency sharing within standard UHF communications networks.

The implementation of the computer simulation model in FORTRAN 77 required some additional effort to be taken in the input/output operations. However, this mild limitation presented no difficulty in the development of this thesis.

Primary Variables of Interest

The user of this model is required to select the values of several different variables; thus, any particular run or series of runs will be expressly tailored to the user's needs. In so doing, each variable value can become the basis for as much in depth testing of the model's results as desired. Four of the variables in this model will be examined in more detail.

One variable is the location of each node. Each of the battalion elements, ECS, ICC, and CRS, can be either

interactively input by the operator or read-in in tabular form from a file. Eight digit grid coordinates are used to describe the unit locations with an accuracy of ten meters. Eleven unit locations are possible but not required since the interconnectivity variables discussed next will determine whether or not a unit location will be used to determine the frequency requirements of the battalion.

Another variable is the network interconnectivity. The interconnections for each node can also be interactively input by the operator or included in the unit location table read-in from a file. The interconnectivity of the network is prescribed by identifying which nodes are linked (which nodes are communicating with one another). A node can be interconnected with a maximum of four other nodes as in the case of the CRS.

The antenna pattern is another variable of interest. Antenna pattern characteristics are developed from a curve fit and input by the operator. The curve fit describes the antenna rejection in decibels as a function of the off-axis angle, in degrees, from the main lobe.

The last variable of interest in this thesis is the frequency rejection characteristics of the receiver. The bandpass rejection characteristics of the receiver are also developed from a curve fit and input by the operator. The concept of this off-frequency rejection allows receiver's reception azimuth to have less of an impact when a potential

interfering signal is off-frequency.

The basic requirements and methodology of the computer simulation model have now been defined. The next chapter, The Simulation Model, will develop the details of the computer model.

IV. THE SIMULATION MODEL

This chapter explains the development of the individual routines of the simulation model. Each routine performs a specific function and calculates data to be used in subsequent routines. The complete code listing for this model is contained in Appendix A.

Figure 2 is a representation of the major routines appearing within the simulation model.

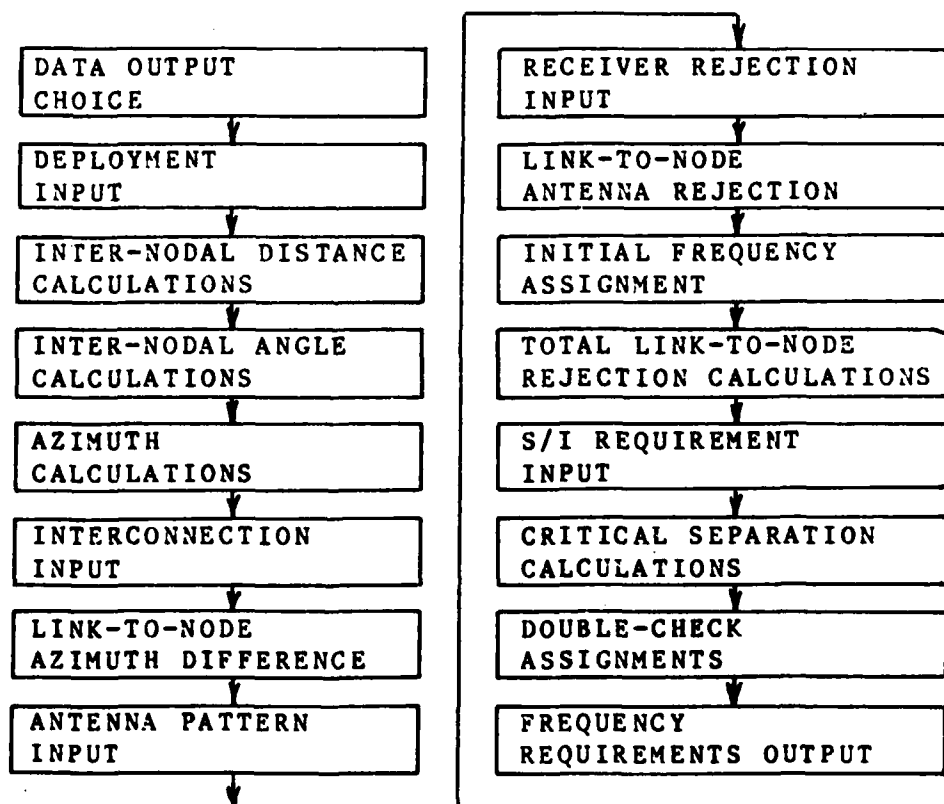


Figure 2. Simulation Model Representation

Data Output Decision

This routine allows the operator to specify what data is to be printed out. All arrays which predicate the final results are available to be printed out. These include the inter-nodal distance array, the inter-nodal angle array, the inter-nodal azimuth array, the interconnection array, the link-to-node azimuth difference array, the link-to-node antenna rejection array, the link-to-node total rejection array, and the initial frequency assignment array.

If only the abbreviated output is required, the output consists of the battalion deployment, the antenna pattern and receiver rejection characteristics, the S/I requirement, the final frequency assignments, and the frequency requirements.

Deployment Input

Each of the battalion elements, ECS, ICC, and CRS, can either be interactively input or read-in in tabular form from a file. Interactive input allows the operator complete freedom in constructing a network to be analyzed. The ability to read the deployment in from a table increases the speed at which runs can be replicated. For ease of input in the interactive mode, the eight digit coordinates are read-in four digits at a time, the easting coordinates first (right) and the northing coordinates second (and up). In the tabular form the coordinates are entered as a single

entity.

Inter-nodal Distance Calculations

The inter-nodal distances are calculated using the Pythagorean Theorem. Each distance is stored in an array to be checked and used to determine propagation losses for desired and interfering signals in a subsequent routine.

Inter-nodal Angle Calculations

The inter-nodal angles are calculated by taking the arctangent of the northing-by-easting differences. Angles of 90, 0, and -90 degrees are initially checked for to preclude the ARCTAN(INFINITY) error condition. Each angle is stored in an array to be checked and used to determine inter-nodal azimuths in the next routine.

Azimuth Calculations

The inter-nodal azimuth calculations are performed by determining which quadrant the azimuth is in and then subtracting the inter-nodal angle in quadrants I and III or adding the inter-nodal angle in quadrants II and IV. Each azimuth is stored in an array to be checked and used as a basis to determine antenna rejection values in subsequent routines.

Interconnection Input

Each of the battalion elements ECS, ICC, and CRS, can be interconnected with up to four nodes. For ease of input, the interconnectivity can be input interactively or in the same table containing the location input. In the interactive mode, the operator is asked the number of interconnections for each node and then asked to input those interconnections. Initial interconnectivity arrays with variable lengths are then constructed to insure the input operation is as user-friendly as possible. An expanded interconnectivity array is then constructed identifying all nodes and whether they are or are not interconnected. This array is stored to be checked and used in subsequent routines when node-to-node links are required.

Link-to-Node Azimuth Difference Calculations

This routine calculates the differences in azimuths between all links and nodes and stores them in a three-dimensional array based upon each unique link vs each unique node. The operation of this routine is explained using Figure 3.

First a check is performed to insure two nodes (I and J) are independent nodes. Then the azimuth difference from the valid link (I-to-J) to each valid node (K and N) is calculated and stored in the three-dimensional array. In Figure 3, valid nodes are nodes independent of the link I-to-J.

This process is then repeated for each link. If the option is selected to print out all the preliminary data, eleven two-dimensional arrays will be output, each array containing the difference between each link with a unique transmitting node, and each node in the deployment.

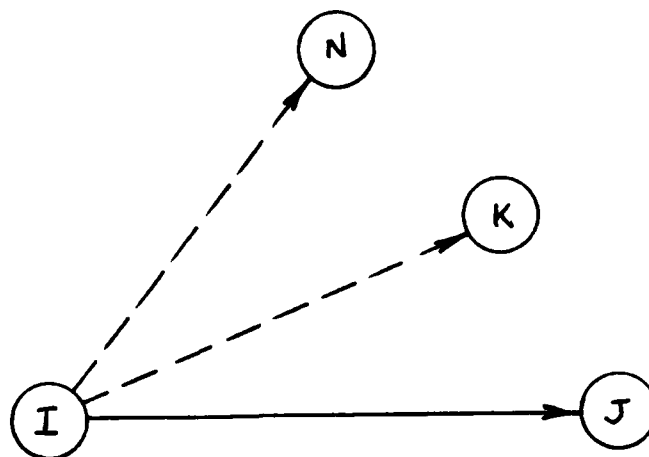


Figure 3. Nodal Relationships

Antenna Pattern Characteristics

In order to determine the antenna rejection at transmitting and receiving nodes, the antenna pattern is required. The PATRIOT AMS utilizes a directional parabolic dish for UHF frequency. An antenna pattern curve-fit provides a description of the characteristics as defined by

$$Y = AB^{**}X$$

where Y is the rejection in db, X is the degrees off main-lobe, and A and B are constants produced by the curve fit. The parameters A and B are interactively input by the

operator.

Receiver Rejection Characteristics

The receiver rejection characteristics are used to determine if a node receiving from two closely situated transmitting nodes will actually be interfered with. A bandpass rejection curve-fit provides a description of the characteristics as defined by

$$Y = A + BX + CX^{**2} + DX^{**3} + EX^{**4} + FX^{**5}$$

where Y is the off-frequency rejection in db, X is the frequency difference, and A through F are constants produced by the curve fit. The parameters A through F are interactively input by the operator.

Link-to-Node Antenna Rejection Calculations

By using the antenna pattern characteristics, the difference in azimuths between each unique link and each unique node in the deployment can be transformed into rejection in db. The link-to-node azimuth difference array is transformed into a link-to-node antenna rejection array as the first step in the process of determining if the S/I requirement will be exceeded, causing interference in place of the desired signal. This array will be used for determining both the transmit and receive antenna rejection, which will be added to the path losses and receiver rejection.

tion to determine the total rejection of interfering nodes by receiving nodes.

Initial Frequency Assignment

The construction of a more efficient frequency assignment algorithm was required in this routine; one that would make maximum use of operational frequencies by permitting sharing whenever possible. The new frequency assignment plan first assigns frequency pair codes to links and then transforms the frequency pair codes into actual frequencies.

Unlike the ABM plan which assigns a frequency code to each node in the network and then assigns a unique frequency to each link depending upon the frequency code of the node, the method developed in this report assigns a frequency code to each link and uses the same frequency pair for each unique frequency code. As a worst case, five unique frequency pairs may be required within the PATRIOT battalion where the maximum communications capability is utilized. An example of this would be in the case where four CRS and one ECS or ICC are interconnected. In this case, to insure that no link assigned a certain frequency code will be connected with a node where another link is assigned that code, the code assignment depicted in Figure 4 may exist.

The frequency pairs are then assigned to the links based upon the unique frequency codes. Frequencies are assigned beginning with 800Mhz. Transmit frequencies are

separated by 5.0Mhz to insure that co-located radios do not provide for transmitter-to-receiver mutual interference (Ref. 10:14). The last transmit frequency and the first receive frequency are separated by 24 Mhz to insure that there is no internal transmitter-to-receiver mutual interference (Ref. 6:2).

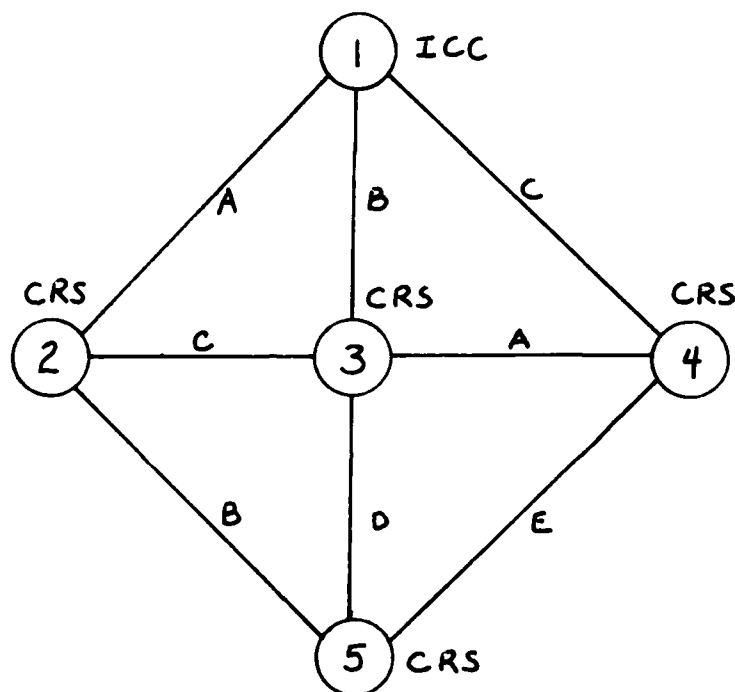


Figure 4. A Worst Case

Total Link-to-Node Rejection

Now that initial frequency assignments have been performed, they must be checked to insure interfering signals will not preclude the reception of desired signals. To make this check, the total rejection of each interfering signal must be calculated. The total rejection is composed of the antenna rejection at the transmitting and receiving nodes,

the path loss difference between the desired and interfering signals, and the bandpass rejection of the receiver. Figure 5 depicts a simple network which will be used to explain this routine.

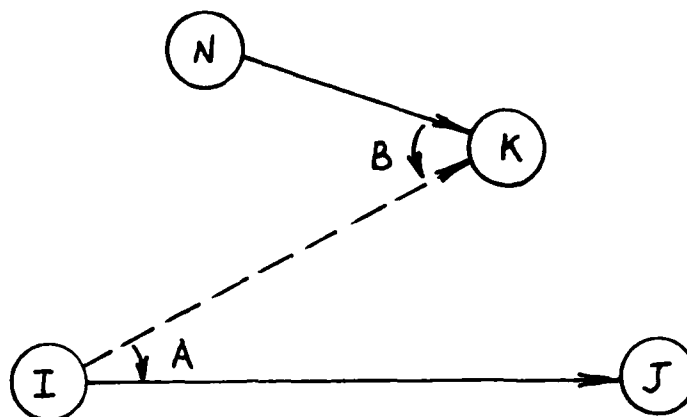


Figure 5. A Simple Network

The angle A provides for a certain amount of rejection in the signal transmitted from node I to node J and received by node K. This rejection is extracted from the antenna rejection array as the value $REJECT(I,J,K)$. The angle B provides for additional rejection in the signal transmitted from node I to node J and received by node K since the antenna at node K is directed toward node N. This rejection is extracted from the antenna rejection array as $REJECT(K,N,I)$. The other two elements of the total rejection are then calculated.

The path loss calculations are performed using procedures previously used in PATRIOT Project Office studies

where

$$\text{PATH LOSS} = 32.5 + 20 \text{ LOG}(\text{DISTANCE}) + 20 \text{ LOG}(\text{FREQUENCY})$$

where the distance is in kilometers and the frequency in megahertz (Ref. 1:4). The path loss difference can be reduced to

$$\text{PATH LOSS DIFFERENCE} = 20 \text{ LOG}(D1 - D2)$$

since the constant subtracts out and the term based upon the frequency difference is of little importance considering the frequencies used. Using the distance array calculated earlier, the path loss is calculated based upon the desired and interfering signals and added to the total rejection. Finally the bandpass rejection is calculated based upon the difference in the desired and interfering signals and added to the total rejection.

S/I Requirement

The signal-to-interference (S/I) requirement or noise figure for the AN/GRC-103 Radio Set is 11db (Ref. 8:1-2). Therefore, the desired signal must be 11db greater than the interfering signal to allow for reception of the desired signal. The S/I requirement is then compared to the total rejection in the next routine to determine which links are not viable due to an interfering signal.

Critical Separation Calculations

This routine determines which links interfere with receiving nodes. To determine which links will cause interference, each node's rejection of each link is checked to insure it is above the S/I requirement. If the S/I requirement is not met, the interfering link, the receiving node, and the rejection are identified to the operator. The link causing the interference is then given a unique frequency and checked to insure it will not cause interference again. The operator is notified that the interfering link has been modified. The frequency assignment algorithms developed in this report are then used to minimize the number of unique frequencies required for the critical links. First, unique frequency codes are assigned to the critical links, and then the critical frequencies are assigned based upon the frequency codes.

Double-check Frequency Assignments

The frequency assignments are again checked to insure that receiving nodes are maintaining their S/I requirement. If there are links causing interference, they are again printed out along with the receiving node and the rejection.

This routine may be overkill since test cases have not shown a problem once critical frequencies have been assigned when required; however, future use will show if this routine may be needed.

Frequency Requirements Output

Once the frequency assignments have been performed, the minimum number of frequencies is output to the operator, as well as those frequencies required.

V. SAMPLE RESULTS

To offer an example of the frequency requirements calculations which this model provides, four PATRIOT battalion deployments will be analyzed. The first three deployments were supplied by the PATRIOT Project Office as currently accepted within the air defense community as representative of PATRIOT deployment planning. The fourth was developed as a typical worst-case deployment. The grid coordinates for these deployments are contained in Appendix A.

Figure 6 depicts the first PATRIOT supplied deployment.

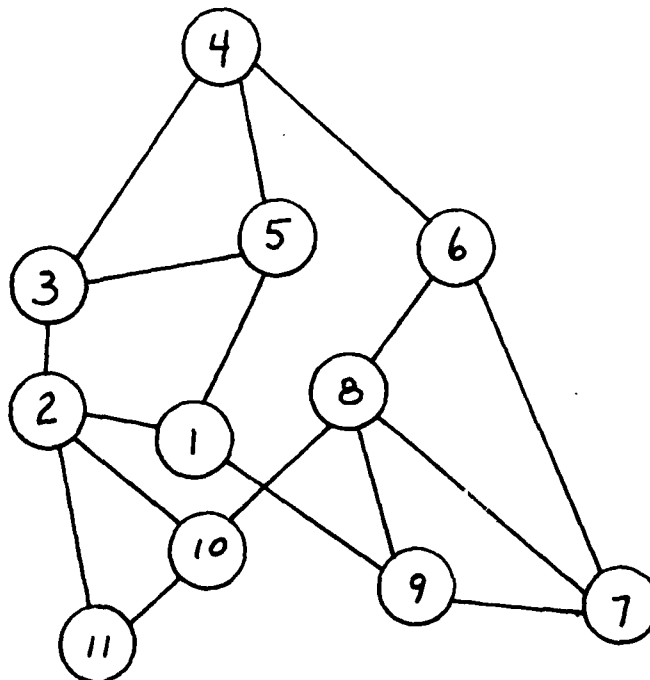


Figure 6. Deployment One

Figure 7 depicts the frequency assignment codes assigned for deployment one. These codes are assigned using the frequency assignment algorithm employing the shared frequency concept developed in this report.

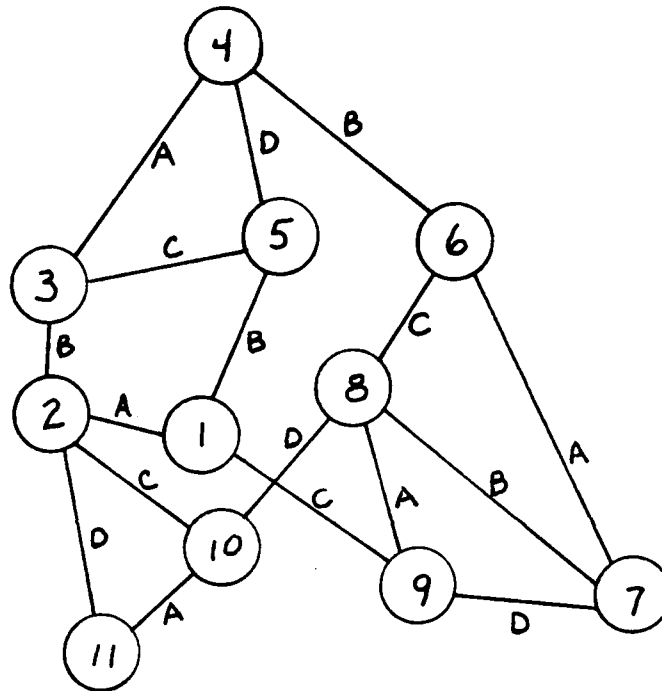


Figure 7. Frequency Assignment Codes for Deployment One

The model predicts that a frequency requirement for only eight frequencies exists when operational frequencies are shared. Analysis of the output reveals that this deployment contains no interfering signals causing the S/I requirement of any one node to be violated, and therefore only the four pairs of frequencies required due to intra-nodal interference are required to support deployment one.

Figure 8 depicts the second PATRIOT supplied deployment. As in the case of the first deployment, the model predicts that only eight frequencies are required to support the UHF communication system. This deployment also contains no interfering signals causing the S/I requirement of any one node to be violated and only four frequency pairs are required due to the frequency assignment algorithm developed in this report.

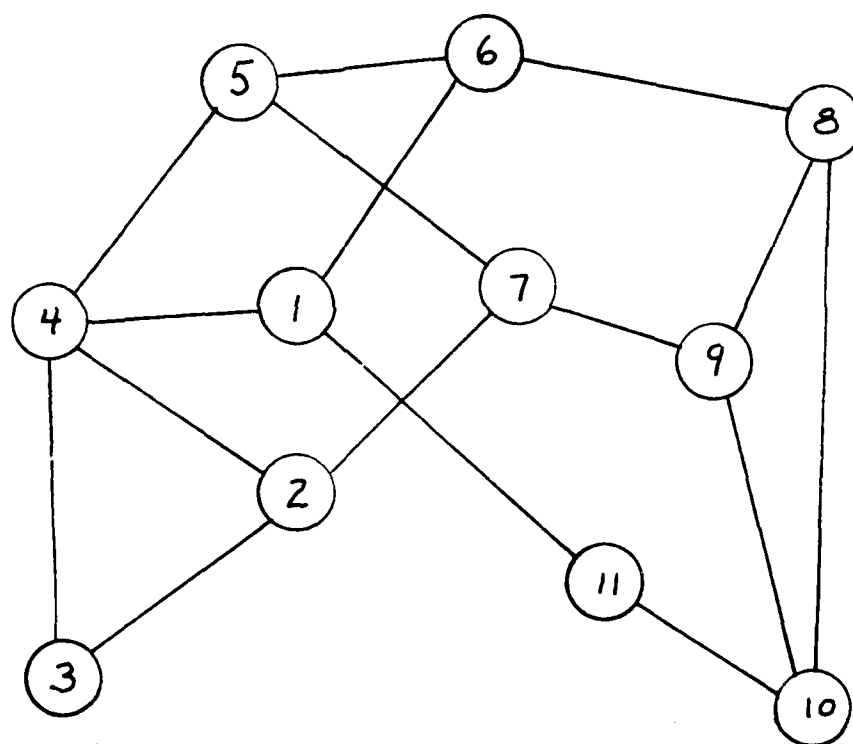


Figure 8. Deployment Two

The minimum number of frequencies theoretically possible for the first two deployments is eight frequencies since at least one CRS in both deployments (Nodes 2 and 8 in the first deployment and Nodes 4 and 9 in the second

deployment), transmit on four operational links. Since each link requires both a transmit and receive frequency, eight frequencies must be required as a minimum in both deployments.

Had the ABM plan been used to assign frequencies to the first deployment, the frequency codes depicted in Figure 9 would be assigned and thirty-four frequencies would be required. Figure 9 also depicts that using ABM methodology would cause a problem once the code 'A' is assigned to node 9 unless some type of an heuristic technique such as a branch-and-bound algorithm is used. Had the ABM plan been used to assign frequencies to the second deployment, thirty-four frequencies would again be required.

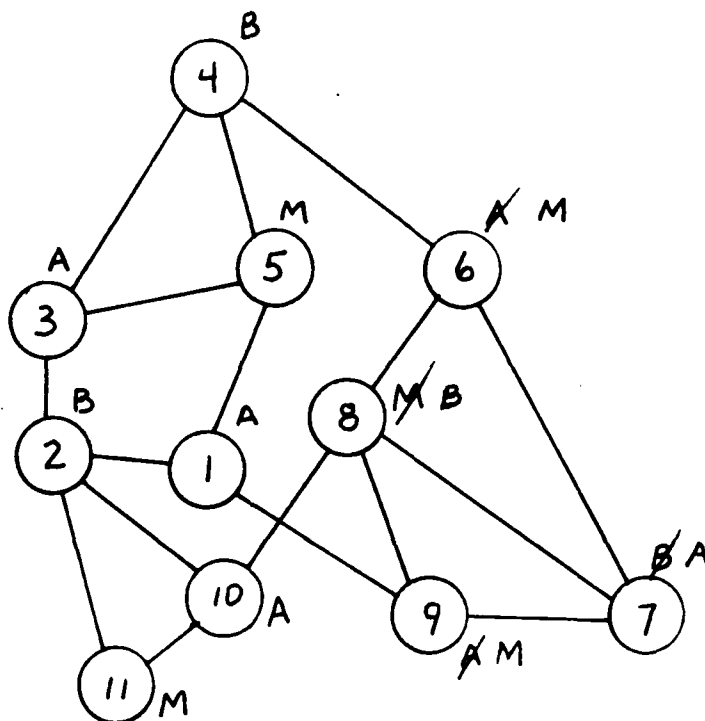


Figure 9. An ABM Problem?

Figure 10 depicts the third PATRIOT supplied deployment. The model predicts that a frequency requirement for ten frequencies exists.

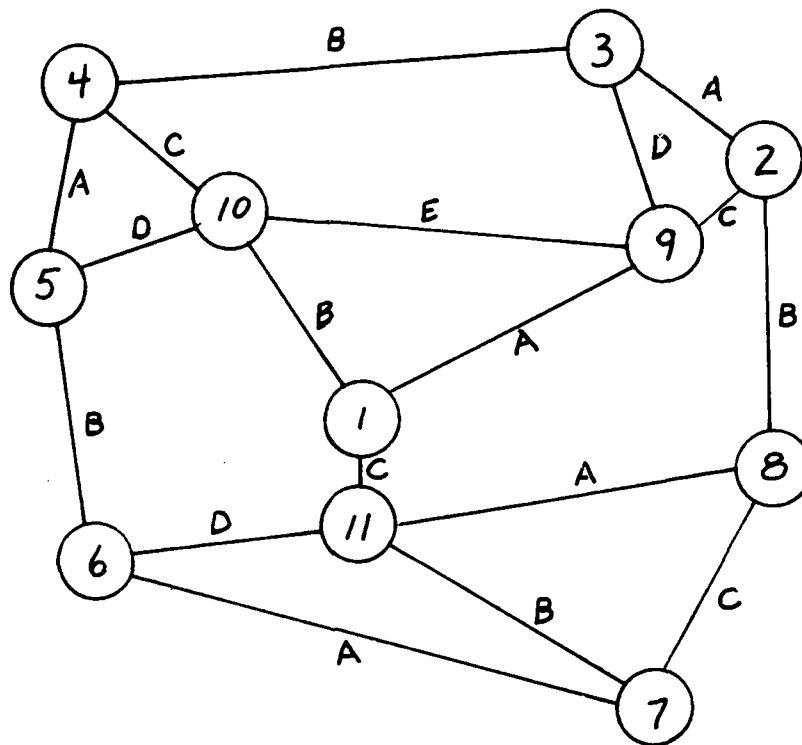


Figure 10. Deployment Three

Also depicted in Figure 10 are the frequency assignment codes. Because of the concentration of communications due to both the proximity of the CRS to each other and the UHF network operating at near capacity, the link from node 9 to node 10 requires a fifth frequency pair. This deployment contains no interfering signals causing the S/I requirement of any node to be violated so that only the ten frequencies required due to intra-nodal interference are required to

support the deployment.

Figure 11 shows one attempt at assigning frequency codes to the third deployment using the ABM plan. Due to the concentration of communication links discussed earlier, the ABM plan will not work. However, had the ABM plan succeeded in assigning frequencies to this deployment, thirty-six unique frequencies would have been required.

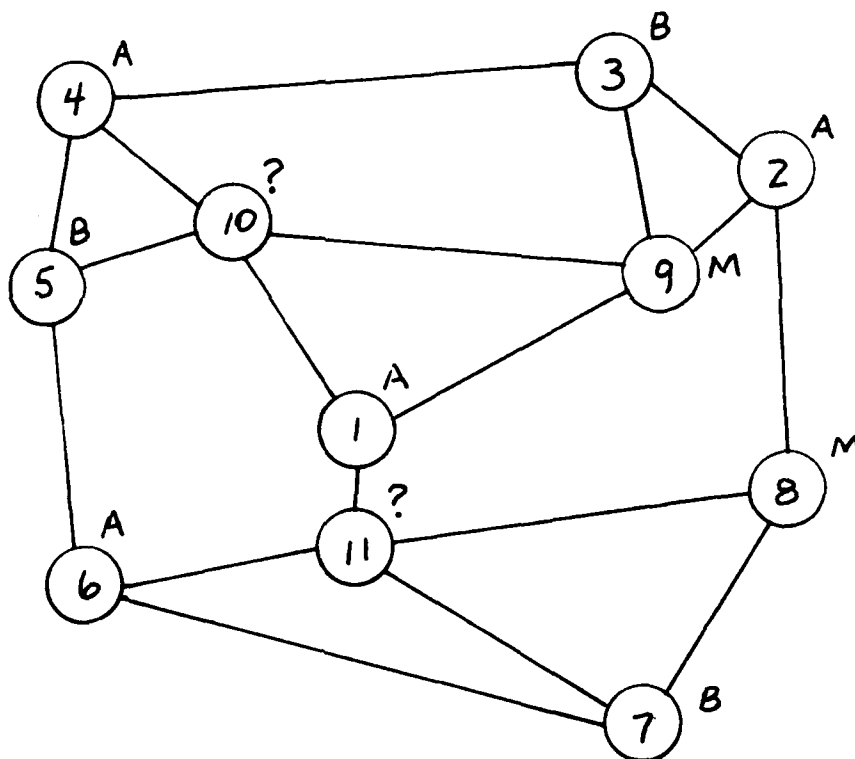


Figure 11. An ABM Attempt

The deployment depicted in Figure 12 is a hypothetical deployment developed to show the critical frequency routine mechanism. The model predicts that a frequency requirement

for nine frequencies exists. Eight of the required frequencies are due to the initial assignment of four frequency pair codes. The ninth frequency is assigned by the critical frequency algorithm.

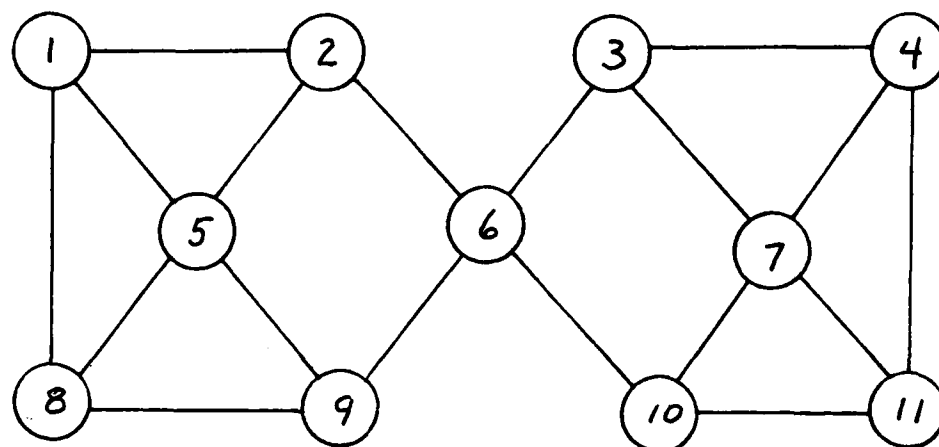


Figure 12. A Worst Case

The initial frequency assignment algorithm assigns both Link 1-to-2 and Link 3-to-4 the same frequency. The rejection algorithms calculate the rejection of link 1-to-2 at node 4 and the rejection of link 4-to-3 at node 1 to be less than the S/I requirement of 11db. This occurs since there is no transmit or receive antenna rejection and no receiver off-frequency bandpass rejection. The only rejection is attributed to path loss. Since the interfering transmitter is 60km from the receiving node and the desired signal is coming from a transmitter 20km away, the rejection due to

the path loss difference is only 9.54db, which violates the S/I requirement of 11db. A unique frequency is then assigned to link 1-to-2 and link 4-to-3, the ninth frequency. It would seem the same situation would exist between nodes 8, 9, 10, and 11 as does for nodes 1, 2, 3, and 4; however, since the initial frequency assignment for link 8-to-9 is not the same as for link 10-to-11, the additional rejection due to the receiver off-frequency rejection allows for the S/I requirement to be exceeded.

VI. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

This research addressed the problem of determining the minimum frequency requirements for a PATRIOT battalion UHF communication system. In an attempt to increase the understanding of the frequency requirements, a computer model was developed to simulate a PATRIOT UHF communication system and the model was subsequently experimented on to predict the frequency requirements. The resulting model, with its appropriate assumptions and constraints, is described in this thesis.

Conclusions

Four goals were set at the beginning of this research in order to measure the degree to which this research succeeded in solving the stated problem. These goals will be separately discussed.

The first goal was to construct a computer model. This goal was met by the writing of a computer program which simulates the PATRIOT battalion UHF communication system. The detailed description of how the model performs this simulation is contained in Chapter IV.

The second goal was to determine, by internal and external verification, that the model behaves properly.

Internal verification was accomplished by rigorous examination of numerous print-outs of the model's data output executed on AFIT's Harris 500. Each table was verified to insure the algorithms for each routine from inter-nodal distance calculations to frequency assignments operated properly and passed the correct set of data to the next routine.

External verification of the model was accomplished by analyzing each algorithm and the resultant output with PATRIOT Project Office representatives. The personnel who participated in this feedback of information were highly qualified PATRIOT system analysts regularly performing data analysis for the PATRIOT Project Office. The model was also validated to a certain degree by the use of CAS Inc. antenna patterns and an adaptation of the path loss calculation algorithms that were used in the CASCUM model.

The third goal, which was the construction of a more efficient frequency assignment algorithm, was performed by developing new frequency assignment methodology by which individual communicating links are assigned unique values so that no links that are directly connected will have the same value. Frequency assignments are then made based upon the unique link values.

The final goal was to draw general conclusions about the minimum UHF frequency requirements for the PATRIOT battalion based upon the model's output. This goal was met by the interpretation of the model's minimum requirements

predictions. As was discussed in Chapter V, the minimum UHF frequency requirements for the PATRIOT battalion can be met with a greatly reduced number of frequencies than would traditionally have been required using the unique frequency assignment concept. In the first two deployments, the frequency requirements have been reduced by 75%, from thirty-four to eight frequencies required. In the third deployment, the ABM plan could not be used to make frequency assignments. Had it succeeded, or a modification of the the ABM plan possible, thirty-six unique frequencies would have been required. This requirement was reduced to ten frequencies, again nearly a 75% reduction in frequency requirements.

Recommendations

As this research effort drew to a close, reflection upon what was accomplished logically led to several ideas which could enhance the benefits to be gained by this simulation model. These ideas are described in this section.

Currently, the model simulates the UHF communication network for a PATRIOT battalion. One idea for improving the model is to allow for multiple battalions to be characterized within the model. This would allow for a further reduction in the number of frequencies required since with the current model, adjacent battalions would require unique frequency blocks to preclude inter-battalion interference. Also the present model has constrained the available

frequencies to a certain list of specific frequencies. However, since available frequencies are actually allocated by system, the frequencies available for assignment must be an additional attribute to be handled by the model.

At this state of model development, a modification of the deployment influences the frequency assignments within the battalion. A logical improvement to this would be to allow flexibility in the frequency assignment algorithms to allow for certain nodes to exit and enter the battalion without restructuring frequency assignments. The frequency assignment algorithm would require an upgrade to check frequency assignments of operating nodes before making an assignment to a new arrival. The assignment algorithm also can be upgraded to check to see if any shared frequency can be used in lieu of a unique frequency when S/I requirements at a node are not met, as in the case of the fourth deployment.

At present, the maximum inter-connection capacity at a node is four links. By increasing this capability, additional air defense systems employing the AN/GRC-103 Radio Set can be simulated. Such a capability seems desirable since the PATRIOT and IHAWK Air Defense Systems will co-exist for a time in the field.

Developing an upgrade of this model with algorithms to profile communication links, such as in the FACTS program, would provide a solid foundation for the development of an

automated system, incorporated in the onboard software, to assist the PATRIOT air defense planners.

Since such a system would include a digitized terrain base, terrain masking algorithms could be incorporated into the rejection calculations. However, since the frequency requirements have been reduced to near theoretical limits of the node itself, such algorithms may not be efficient.

It may soon be feasible to validate this model using the PATRIOT system. Such testing would substantiate the operation of this model so that work on an automated system, so badly needed, could progress.

One final recommendation is required. It is recommended that a model such as this one not be used in a tactical environment without a threat analysis to determine the implications of using a limited number of shared frequencies. A further discussion of this subject is beyond the scope of this report.

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APPENDIX A

GRID COORDINATES AND CODE LISTING

The first two pages of this appendix contain the grid coordinates for the deployments analyzed in Chapter V. The remaining pages of this appendix contain the code listing for this computer simulation model.

Deployment One

	COORDINATES	LINKS
ICC	06045190	2 5 9
ECS	01555280	1 3 11 10
ECS	01965763	2 4 5
ECS	11007300	3 5 6
ECS	12556035	1 3 4
ECS	16166000	4 8 7
ECS	30504135	6 8 9
CRS	14955498	6 7 9 10
CRS	17554205	1 7 8
CRS	06474400	2 8 11
CRS	02003800	2 10

Deployment Two

08501905	4 6 11
08501500	3 4 7
00000700	2 4
03001800	2 3 5 1
10602790	4 6 7
15502660	1 5 8
12501950	2 5 9
33002450	6 9 10
25601740	7 8 10 11
22500750	8 9 11
16850825	1 9 10

Deployment Three

28383831	9	10	11	
38454714	3	8	9	
29734921	2	4	9	
12714189	3	5	10	
10743873	4	6	10	
14182674	5	7	11	
34892793	6	8	11	
37153676	2	7	11	
34214485	1	2	3	10
21423800	1	4	5	9
26253375	1	6	7	8

Deployment Four

00002000	2	5	8	
20002000	1	5	6	
40002000	6	7	4	
60002000	3	7	11	
10001000	1	2	8	9
30001000	2	9	3	10
50001000	3	4	10	11
00000000	1	5	9	
20000000	5	8	6	
40000000	6	7	11	
60000000	4	7	10	

PROGRAM FREQUED

PROGRAM FREQUED READS IN A SET OF COORDINATES FOR 11 COMMUNICATING
 NODES AND WHAT 4 NODES ARE INTERCONNECTED, AND OUTPUTS THE MINIMUM
 NUMBER OF FREQUENCIES REQUIRED TO SUPPORT THE UHF COMMUNICATION
 SYSTEM

VARIABLE DECLARATIONS

X(I) LASTING COORDINATES FOR NODES
 Y(I) NORTHING COORDINATES FOR NODES
 LONK(I) GRID COORDINATES FOR NODES
 D(I,J) ARRAY CONTAINING DISTANCES BETWEEN NODES I AND J
 ANG(I,J) ARRAY CONTAINING ANGLES BETWEEN NODES I AND J
 AZ(I,J) ARRAY CONTAINING AZIMUTHS BETWEEN NODES I AND J
 P1 3.1415927
 CONNECT(I,J) ARRAY SHOWING WHICH NODES ARE CONNECTED
 LINK(I,J) ARRAY SHOWING WHICH NODES ARE CONNECTED AND WHICH NOT
 AZDIFF(I,J,K) ARRAY CONTAINING DIFFERENCES IN AZIMUTH BETWEEN
 LINKS(I,J) AND NODES(K)
 REJECT(I,J,K) ARRAY CONTAINING THE SEPARATION IN DB BETWEEN
 LINKS(I,J) AND NODES(K) BASED UPON ANTENNA REJECTION AT THE
 LINK(I,J)
 TOTREJ(I,J,K) ARRAY CONTAINING THE SEPARATION IN DB BETWEEN
 LINKS(I,J) AND NODES(K) BASED UPON THE ANTENNA REJECTION AT
 LINK(I,J) AND NODE(K), AND THE PROPAGATION LOSS BETWEEN
 LINKS(I,K) AND (N,K)
 MIN THE MINIMUM SEPARATION IN DB BETWEEN THE NODE(K) AND
 THE LINK(I,J)
 SIGLOSS THE FREE SPACE PATH LOSS OF THE DESIRED SIGNAL DUE
 TO DISTANCE
 INTLOSS THE FREE SPACE PATH LOSS OF THE INTERFERING SIGNAL
 DUE TO DISTANCE
 SIREU THE SIGNAL TO INTERFERENCE REQUIREMENT
 CRITERJ THE S/I REQUIREMENT MINUS THE TOTAL REJECTION
 N,B PARAMETERS TO CURVE FIT THE ANTENNA PATTERN
 C MAXIMUM SIDELOBE REJECTION OF ANTENNA
 AA,BB,CC,DD,EE,FF PARAMETERS TO CURVE FIT THE REJECTION PATTERN


```

61 * I,J,K,N LOOP COUNTERS
62 * NUMCRIT THE NUMBER OF UNIQUE FREQUENCIES REQUIRED FOR THE LINKS WHICH
63 * DO NOT EXCEED THE S/I REQUIREMENT
64 * MAXLINKS THE MAXIMUM NUMBER OF LINKS FOR A NODE
65 * NUMFREQ THE NUMBER OF FREQUENCIES REQUIRED TO SUPPORT
66 * THE COMMUNICATION NETWORK
67 * FREQUIDF DIFFERENCE IN FREQUENCIES BETWEEN TWO TRANSMITTERS
68 * FREQUEJ FREQUENCY REJECTION IN DB
69 * FREQ(I,J) ARRAY HOLDING FREQUENCY ASSIGNMENTS
70 * PROBLEM VARIABLE TO ENSURE 24MHZ FREQUENCY SEPARATION MET
71 * DEPIN FLAG TO DETERMINE IF DEPLOYMENT INPUT IS INTERACTIVE
72 * FLAG FLAG TO DETERMINE IF ARRAYS ARE TO BE PRINTED OUT
73 * MAX THE MAXIMUM SEPARATION IN KM BETWEEN THE NODE(K) AND
74 * THE NODES IT COMMUNICATES WITH
75 * NUMITS NUMBER OF UNITS IN DEPLOYMENT
76 *
77 REAL X(1:11),Y(1:11),COORD(1:11),D(1:11,1:11)
78 REAL ANG(1:11,1:11),AZ(1:11,1:11)
79 REAL P1,CONNECT(1:11,1:4),LINK(1:11,1:11)
80 REAL AZDIFF(1:11,1:11,1:11),REJECT(1:11,1:11,1:11)
81 REAL TOTREJ(1:11,1:11,1:11),MIN,SIGLOSS,INTLOSS
82 REAL SIREQ,CRTIREJ,FREQ(1:11,1:11),PROBLEM,MAX
83 CHARACTER FLAG*1,DEPIN*1
84 INTEGER I,J,K,N,NUMCRIT,MAXLINKS,NUMFREQ
85 INTEGER*6 COORD
86 PI=3.1415927
87 IN=5
88 PRINT *, ' '
89 PRINT *, ' '
90 PRINT *, ' '
91 PRINT *, ' '
92 PRINT *, ' '
93 PRINT *, ' '
94 * DETERMINE IF DEPLOYMENT INPUT TO BE INTERACTIVE
95 *
96 PRINT *, 'IS DEPLOYMENT INPUT INTERACTIVE? Y(ES) OR N(O)'
97 READ (*, '(A)') DEPIN
98
99
100

```

```

105 IF (DEFIN.EQ.'N') THEN
106   GO TO 105
107 END IF
108
109
110
111
112
113
114 *
115 * WHAT DATA TO BE PRINTED OUT IF INTERACTIVE
116 *
117 PRINT *, 'DO YOU WANT ALL ARRAYS PRINTED OUT? Y(YES) OR N(0)'
118 READ (*, '(A1)') FLAG
119 *
120 * INTERACTIVELY READ IN GRID COORDINATES
121 *
122 NUNITS=11
123 DO 105 I=1,11
124   WRITE (*,40) I
125   40 FORMAT (' ENTER EASTING COORDINATES FOR NODE ',I2)
126   READ *,X(I)
127   WRITE (*,50) I
128   50 FORMAT (' ENTER NORTHING COORDINATES FOR NODE ',I2)
129   READ *,Y(I)
130   PRINT *,', '
131   PRINT *,', '
132 105 CONTINUE
133 IF (DEFIN.EQ.'Y') THEN
134   GO TO 205
135 END IF
136 *
137 * READ INPUT FROM TABLE
138 *
139 READ (IN,7) NUNITS,FLAG
140 7 FORMAT (I2,1X,I4)
141 PRINT *,', '
142 PRINT *,', '
143 PRINT *,', '
144 PRINT *,', '
145 WRITE (OUT,1200) NUNITS
146 1200 FORMAT ('NUMBER OF UNITS IN DEPLOYMENT IS: ',I5)
147 DO 205 I=1,NUNITS
148   READ (IN,1001) X(I),Y(I),(CONNECT(I,J),J=1,4)
149
150
151

```

```

156      1001  FORMAT (2F4.0,2X,4(F2.0,1X))
157      124 205  CONTINUE
158
159      165 *      ECHO THE COORDINATES
160
161      PRINT *, ' '
162      DO 305 I=1,11
163          COOR(I)=X(I)+1000+Y(I)
164          COORD=COOR(I)
165          WRITE (OUT,20) I,COORD
166      20  FORMAT (' NODE',2X,12,2X,'COORDINATES',3X,10)
167      305  CONTINUE
168
169      175 *      CALCULATE THE DISTANCE BETWEEN THE NODES IN KILOMETERS
170
171      DO 200 I=1,NUNITS
172          DO 200 J=1,NUNITS
173              D(I,J)=(SQRT((X(I)-X(J))**2+(Y(I)-Y(J))**2))/100
174              CONTINUE
175          WRITE (OUT,5)
176
177      200  PRINT OUT THE DISTANCES BETWEEN THE NODES
178
179      IF (FLAG.EQ.'N') THEN
180          GO TO 300
181      END IF
182      WRITE (OUT,60)
183      FORMAT (32X,'DISTANCE (KM) BETWEEN NODES')
184      WRITE (OUT,70) (I,I=1,NUNITS)
185      FORMAT (12X,11(' NODE',12,2X))
186      WRITE (OUT,5)
187      DO 300 I=1,NUNITS
188          WRITE (OUT,10) I,(D(I,J),J=1,NUNITS)
189          FORMAT (' NODE',12,3X,11F8.2)
190          WRITE (OUT,5)
191          WRITE (OUT,5)
192      300  CONTINUE
193
194      200  CONTINUE
195
196      200  CONTINUE
197
198      200  CONTINUE
199
200  CONTINUE

```

```

207 *
208 *
209 *
210 *
211 *
212 *
213 *
214 *
215 * CALCULATE THE ANGLES BETWEEN THE NODES
216 *
217 * DO 400 I=1,NUNITS
218 * DO 400 J=1,NUNITS
219 * IF ((X(J)-X(I)).EQ.0.AND.(Y(J)-Y(I)).GT.0) THEN
220 *   ANG(I,J)=90.0
221 * ELSE IF ((X(J)-X(I)).EQ.0.AND.(Y(J)-Y(I)).EQ.0) THEN
222 *   ANG(I,J)=0.0
223 * ELSE IF ((X(J)-X(I)).EQ.0.AND.(Y(J)-Y(I)).LT.0) THEN
224 *   ANG(I,J)=-90.0
225 * END IF
226 * IF ((X(J)-X(I)).EQ.0) THEN
227 *   GO TO 400
228 * END IF
229 * ANG(I,J)=ATAN((Y(J)-Y(I))/(X(J)-X(I)))*180/PI
230 * 400 CONTINUE
231 * WRITE (OUT,5)
232 *
233 * PRINT OUT THE ANGLES BETWEEN THE NODES
234 *
235 * IF (FLAG.EQ.'N') THEN
236 *   GO TO 500
237 * END IF
238 * WRITE (OUT,90)
239 * 90 FORMAT (32X,'ANGLE (DEGREES) BETWEEN NODES')
240 * WRITE (OUT,11) (I,I=1,NUNITS)
241 * 11 FORMAT (12X,11('NODE',12,2X))
242 * WRITE (OUT,5)
243 * DO 500 I=1,NUNITS
244 *   WRITE (OUT,80) I,(ANG(I,J),J=1,NUNITS)
245 *   80 FORMAT (' NODE',12,3X,11F8.2)
246 *   WRITE (OUT,5)
247 *   WRITE (OUT,5)
248 * 500 CONTINUE
249 *
250 * CONVERT THE ANGLES BETWEEN NODES TO AZIMUTHS BETWEEN THE NODES
251 *
252 *
253 *

```

```

258      DO 101 I=1,NUNITS
259      DO 101 J=1,NUNITS
260      IF ((Y(J)-Y(I)).GE.0.AND.(X(J)-X(I)).GE.0) THEN
261      AZ(I,J)=90.0-ANG(I,J)
262      ELSE IF ((Y(J)-Y(I)).LT.0.AND.(X(J)-X(I)).GE.0) THEN
263      AZ(I,J)=90.0+ABS(ANG(I,J))
264      ELSE IF ((Y(J)-Y(I)).LT.0.AND.(X(J)-X(I)).LT.0) THEN
265      AZ(I,J)=270.0-ANG(I,J)
266      ELSE
267      AZ(I,J)=270.0+ABS(ANG(I,J))
268      END IF
269      CONTINUE
270      WRITE (OUT,5)
271      PRINT OUT THE AZIMUTHS BETWEEN THE NODES
272      IF (FLAG.EQ.'N') THEN
273      GO TO 600
274      END IF
275      WRITE (OUT,21)
276      FORMAT (37X,'AZIMUTH (DEGREES) BETWEEN NODES')
277      WRITE (OUT,31) (I,I=1,NUNITS)
278      FORMAT (12X,11('NODE',I2,2X))
279      WRITE (OUT,5)
280      DO 600 I=1,NUNITS
281      WRITE (OUT,41) I,(AZ(I,J),J=1,NUNITS)
282      FORMAT(' NODE',I2,3X,11F8.2)
283      WRITE (OUT,5)
284      CONTINUE
285      IF (DEPIN.EQ.'N') THEN
286      GO TO 700
287      END IF
288      INITIALIZE AN ARRAY TO SHOW WHICH NODES ARE INTERCONNECTED

```

```

317 DO 800 I=1,11
318 DO 800 J=1,4
319 CONNECT(I,J)=0
320 CONTINUE
321 WRITE (OUT,5)
322 *
323 * READ IN WHICH NODES ARE INTERCONNECTED
324 *
325 DO 700 I=1,11
326 WRITE (*,51) I
327 FORMAT(' HOW MANY NODES CONNECT TO NODE',I2)
328 READ *,N
329 WRITE (*,61) N
330 FORMAT(' NOW ENTER THE',I2,' NODES BY NUMBER')
331 READ *,(CONNECT(I,J),J=1,N)
332 PRINT *,
333 700 CONTINUE
334 *
335 * IDENTIFY WHICH NODES ARE INTERCONNECTED AND WHICH ARE NOT
336 *
337 DO 900 I=1,NUNITS
338 DO 900 J=1,NUNITS
339 IF (CONNECT(I,1).EQ.J.OR.CONNECT(I,2).EQ.J.
340 + OR.CONNECT(I,3).EQ.J.OR.CONNECT(I,4).EQ.J) THEN
341 LINK(I,J)=1.0
342 ELSE
343 LINK(I,J)=0.0
344 END IF
345 CONTINUE
346 WRITE (OUT,5)
347 *
348 * PRINT OUT WHICH NODES ARE INTERCONNECTED
349 *
350 IF (FLAG.EQ.'N') THEN
351 GO TO 201
352 END IF
353 WRITE (OUT,71)

```

```

1301      21      FORMAT (37X,'CONNECTED NODES')
1302      WRITE (OUT,81) (I,I=1,NUNITS)
1303      FORMAT (12X,11('NODE',I2,2X))
1304      WRITE (OUT,5)
1305      DO 201 I=1,NUNITS
1306      WRITE (OUT,91) I,(LINK(I,J),J=1,NUNITS)
1307      FORMAT(' NODE',I2,2X,11F8.2)
1308      WRITE (OUT,5)
1309      WRITE (OUT,5)
1310      201      CONTINUE
1311
1312      22      *      INITIALIZE AN ARRAY TO STORE THE DIFFERENCE IN AZIMUTHS BETWEEN
1313      23      *      LINKS AND NODES.  USE -1 SINCE 0.0 IS POSSIBLE IF THE AZIMUTH
1314      24      *      DIFFERENCE IS 0.0
1315      DO 401 I=1,NUNITS
1316      DO 401 J=1,NUNITS
1317      DO 401 K=1,NUNITS
1318      AZDIFF(I,J,K)=-1
1319      401      CONTINUE
1320
1321      *      IDENTIFY THE DIFFERENCES IN AZIMUTHS BETWEEN ALL LINKS AND NODES
1322      DO 301 I=1,NUNITS
1323      DO 301 J=1,NUNITS
1324      DO 301 K=1,NUNITS
1325      IF (I.EQ.J) THEN
1326      GO TO 301
1327      END IF
1328      IF (LINK(I,J).EQ.1.0) THEN
1329      DO 501 K=1,11
1330      IF ((I.EQ.K).OR.(J.EQ.K)) THEN
1331      GO TO 501
1332      END IF
1333      AZDIFF(I,J,K)=ABS(AZ(I,J)-AZ(I,K))
1334      501      CONTINUE
1335      301      CONTINUE
1336      401      CONTINUE

```

```

119 IF (AZDIFF(I,J,K).GE.180.0) THEN
120   AZDIFF(I,J,K)=360.0-AZDIFF(I,J,K)
121   END IF
122   CONTINUE
123   END IF
124   CONTINUE
125 * PRINT DIFFERENCES IN AZIMUTHS BETWEEN ALL LINKS AND NODES
126 *
127 IF (FLAG.EQ.'N') THEN
128   GO TO 601
129 END IF
130 DO 601 I=1,NUNITS
131   WRITE (OUT,5)
132   WRITE (OUT,12)
133   FORMAT (37X,'SEPARATION BETWEEN LINKS AND NODES')
134   WRITE (OUT,22) (N,N=1,NUNITS)
135   FORMAT (12X,11('NODE',I2,2X))
136   WRITE (OUT,5)
137   DO 601 J=1,NUNITS
138     WRITE (OUT,32) I,J,(AZDIFF(I,J,K),K=1,NUNITS)
139     FORMAT(' LINK',I2,'-',J2,11F8.2)
140     WRITE (OUT,5)
141     WRITE (OUT,5)
142   601 CONTINUE
143 *
144 * ANTENNA PATTERN CHARACTERISTICS
145 *
146   WRITE (OUT,5)
147   WRITE (OUT,5)
148   WRITE (OUT,1000)
149   1000 FORMAT(' THE ANTENNA PATTERN IS DEFINED AS: ',/
150     + ' REJECTION(IN DB)=A*(B+DEGREES OFF MAINLOBE)"/,
151     + ' REJECTION CANNOT EXCEED MAXIMUM SIDELOBE OF C"/,/)
152   PRINT *,/
153   PRINT *,/ ENTER THE VALUE FOR A'
154   READ *,A
155

```



```

462 PRINT *, '
463 PRINT *, ' ENTER THE VALUE FOR B'
464 READ *, B
465 PRINT *, '
466 PRINT *, ' ENTER THE VALUE FOR C'
467 READ *, C
468 WRITE (OUT,5)
469 WRITE (OUT,5)
470 *
471 * FREQUENCY REJECTION CHARACTERISTICS OF THE RECEIVER
472 *
473 WRITE (OUT,5)
474 WRITE (OUT,5)
475 WRITE (OUT,1400)
476 FORMAT ( " THE BANDPASS REJECTION IS DEFINED AS :",/,
477 + " REJECTION(IN DB)=A+B*FREQDIF+C*FREQDIF**2+",/,
478 + " D*FREQDIF**3+E*FREQDIF**4+F*FREQDIF**5)",//)
479 PRINT *, '
480 PRINT *, ' ENTER THE VALUE FOR A'
481 READ *, AA
482 PRINT *, '
483 PRINT *, ' ENTER THE VALUE FOR B'
484 READ *, BB
485 PRINT *, '
486 PRINT *, ' ENTER THE VALUE FOR C'
487 READ *, CC
488 PRINT *, '
489 PRINT *, ' ENTER THE VALUE FOR D'
490 READ *, DD
491 PRINT *, '
492 PRINT *, ' ENTER THE VALUE FOR E'
493 READ *, EE
494 PRINT *, '
495 PRINT *, ' ENTER THE VALUE FOR F'
496 READ *, FF
497 WRITE (OUT,5)
498 WRITE (OUT,5)

```

CONSTRUCT AN ARRAY IDENTIFYING THE REJECTION AT EACH LINK
FOR EACH NODE

```

DO 701 I=1,NUNITS
  DO 701 J=1,NUNITS
    DO 701 K=1,NUNITS
      IF (AZDIFF(I,J,K).EQ.-1) THEN
        REJECT(I,J,K)=-1
      ELSE
        REJECT(I,J,K)=A*(B**AZDIFF(I,J,K))
        IF (REJECT(I,J,K).GT.C) THEN
          REJECT(I,J,K)=C
        END IF
      END IF
    END IF
  END IF
END IF

```

PRINT REJECTION AT EACH LINK FOR EACH NODE

```

IF (FLAG.EQ.'N') THEN
  GO TO 801
END IF
DO 801 I=1,11
  WRITE (OUT,5)
  WRITE (OUT,42)
  FORMAT(37X,'REJECTION BETWEEN LINKS AND NODES')
  WRITE (OUT,52) (N,N=1,NUNITS)
  FORMAT (12X,11('NODE',12,2X))
  WRITE (OUT,5)
DO 801 J=1,NUNITS
  WRITE (OUT,52) I,J,(REJECT(I,J,K),K=1,NUNITS)
  FORMAT (' LINK',12,'-',12,1F8.2)
  WRITE (OUT,5)
  WRITE (OUT,5)

```

```

571 H01 CONTINUE
572 *
573 * CONSTRUCT AN ARRAY IDENTIFYING THE TOTAL REJECTION AT EACH LINK
574 * FOR EACH NODE
575 *
576 DO 901 I=1,NUNITS
577 DO 901 J=1,NUNITS
578 DO 901 K=1,NUNITS
579 TOTREJ(I,J,K)=REJECT(1,J,K)
580 901 CONTINUE
581 *
582 * ASSIGN FREQUENCIES TO LINKS BASED UPON MY ABCDE PLAN
583 *
584 *
585 * INITIALIZE THE ASSIGNMENT ARRAY
586 *
587 MAXLINKS=0
588 DO 702 I=1,NUNITS
589 DO 702 J=1,NUNITS
590 FREQ(I,J)=LINK(I,J)-1.0
591 702 CONTINUE
592 *
593 * ASSIGN FREQUENCY PAIRS TO LINKS
594 *
595 DO 802 I=1,NUNITS
596 DO 802 J=1,NUNITS
597 IF (FREQ(I,J).EQ.0) THEN
598 DO 902 N=1,NUNITS
599 IF (FREQ(I,N).EQ.1.OR.FREQ(J,N).EQ.1) THEN
600 GO TO 1
601 END IF
602 CONTINUE
603 FREQ(I,J)=1
604 FREQ(J,I)=1
605 GO TO 6
606 1
607 DO 103 N=1,11
608 IF (FREQ(I,N).EQ.2.OR.FREQ(J,N).EQ.2) THEN

```

```

        GO TO 2
      END IF
    CONTINUE
    FREQ(I,J)=2
    FREQ(J,I)=2
    GO TO 6
  DO 203 N=1,NUNITS
    IF (FREQ(I,N).EQ.3.OR.FREQ(J,N).EQ.3) THEN
      GO TO 3
    END IF
    CONTINUE
    FREQ(I,J)=3
    FREQ(J,I)=3
    GO TO 6
  DO 303 N=1,NUNITS
    IF (FREQ(I,N).EQ.4.OR.FREQ(J,N).EQ.4) THEN
      GO TO 9
    END IF
    CONTINUE
    FREQ(I,J)=4
    FREQ(J,I)=4
    GO TO 6
  DO 403 N=1,NUNITS
    IF (FREQ(I,J).GT.MAXLINKS) THEN
      MAXLINKS=FREQ(I,J)
    END IF
    CONTINUE
  DO 403 I=1,NUNITS
  DO 403 J=1,NUNITS
    IF (FREQ(I,J).GT.0.AND.FREQ(I,J).LE.5) THEN

```

* ASSIGN FREQUENCIES TO LINKS - THIS PROGRAM DEFAULTS TO A SEED
 * OF 800MHZ WITH 24MHZ SEPARATION BETWEEN XMITTER-RCVR SAME RADIO
 * AND 5 MHZ XMITTER-RCVR CO-LOCATED RADIOS

```

667 IF (FREQ(I,J).EQ.1) THEN
668   FREQ(I,J)=800.0
669   FREQ(J,I)=844.0
670 ELSE IF (FREQ(I,J).EQ.2) THEN
671   FREQ(I,J)=805.0
672   FREQ(J,I)=849.0
673 ELSE IF (FREQ(I,J).EQ.3) THEN
674   FREQ(I,J)=810
675   FREQ(J,I)=854
676 ELSE IF (FREQ(I,J).EQ.4) THEN
677   FREQ(I,J)=815
678   FREQ(J,I)=859
679 ELSE IF (FREQ(I,J).EQ.5) THEN
680   FREQ(I,J)=820
681   FREQ(J,I)=864
682 END IF
683 END IF
684 CONTINUE
685 * NOW IDENTIFY THE REJECTION AT EACH NODE FOR EACH LINK AND ADD THE
686 * MINIMUM ANTENNA REJECTION, PATH LOSS, AND FREQUENCY REJECTION
687 * TO THE TOTAL REJECTION ARRAY
688 DO 102 I=1,NUNITS
689   DO 102 J=1,NUNITS
690     DO 102 K=1,NUNITS
691       MIN=100.0
692       IF (K.NE.N.AND.I.NE.K) THEN
693         SIGLOSS=20.0*(ALOG10(D(K,N)))
694         INFLOSS=20.0*(ALOG10(D(I,K)))
695         FREQDIFF=ABS(FREQ(I,J)-FREQ(N,K))
696         FREQREJ=AA+BB*FREQDIFF+CC*REJDIFF**2+DD*FREQDIFF**3+
697           EE*FREQDIFF**4+FF*FREQDIFF**5
698         IF (FREQREJ.GT.30.0) THEN
699           FREQREJ=30.
700         END IF
701         IF (FREQDIFF.LI.1.) THEN
702           *
703           +
704           +
705           +
706           +
707           +
708           +
709           +
710           +
711           +

```

```

218 FREQREJ=0.0
219 END IF
220 IF ((LINK(K,N).EQ.1.0).AND.(REJECT(I,J,K).GE.0).
221 + AND.(REJECT(K,N,I)-SIGLOSS+FREQREJ).LT.MIN.AND.
222 + REJECT(K,N,I).GE.0) THEN
223 MIN=REJECT(K,N,I)-SIGLOSS+FREQREJ
224 END IF
225 IF (LINK(K,N).EQ.1.AND.N.EQ.1.
226 + AND.REJECT(I,J,K).GE.0) THEN
227 MIN=0.0-SIGLOSS+FREQREJ
228 END IF
229 END IF
230 CONTINUE
231 IF (MIN.EQ.100.0) THEN
232 GO TO 102
233 END IF
234 TOTREJ(I,J,K)=TOTREJ(I,J,K)+MIN+INTLOSS
235 CONTINUE
236 * PRINT THE TOTAL REJECTION AT EACH LINK FOR EACH NODE
237 IF (FLAG.EQ.'N') THEN
238 GO TO 502
239 END IF
240 CONTINUE
241 DO 502 I=1,NUNITS
242 WRITE (OUT,5)
243 WRITE (OUT,13)
244 FORMAT (37X,'TOTAL REJECTION BETWEEN LINKS AND NODES')
245 WRITE (OUT,23) (N,N=1,NUNITS)
246 FORMAT (12X,11('NODE',I2,2X))
247 WRITE (OUT,5)
248 DO 502 J=1,NUNITS
249 WRITE (OUT,33) I,J,(TOTREJ(I,J,K),K=1,NUNITS)
250 FORMAT (' LINK',I2,'-',J2,11F8.2)
251 WRITE (OUT,5)
252 END

```

```

275 502 CONTINUE
276 *
277 * PRINT OUT FREQUENCY ASSIGNMENTS NOT CONSIDERING CRITICAL LINKS
278 *
279 IF (FLAG.EQ.'N') THEN
280 GO TO 503
281 END IF
282 WRITE (OUT,5)
283 WRITE (OUT,63)
284 63 FORMAT (37X,'FREQUENCY ASSIGNMENTS W/O CRITICAL LINKS')
285 WRITE (OUT,73) (1,1=1,NUNITS)
286 73 FORMAT (12X,11('NODE',12,2X))
287 WRITE (OUT,5)
288 DO 503 I=1,NUNITS
289 WRITE (OUT,83) 1,(FREQ(I,J),J=1,NUNITS)
290 83 FORMAT (' NODE',12,2X,11F8.2)
291 WRITE (OUT,5)
292 WRITE (OUT,5)
293 503 CONTINUE
294 *
295 * S/I REQUIREMENT FOR AN/GRC-103 IS 11.0 DB
296 *
297 WRITE (OUT,5)
298 WRITE (OUT,1010)
299 1010 FORMAT (' THE S/I REQUIREMENT FOR AN/GRC-103 IS 11.0 DB')
300 SIKER=11.0
301 WRITE (OUT,5)
302 WRITE (OUT,5)
303 *
304 * IDENTIFY CRITICAL SEPARATIONS BETWEEN LINKS AND NODES-
305 * SEPARATIONS WHICH DO NOT ALLOW FOR 11.0 DB OF REJECTION
306 *
307 DO 602 I=1,NUNITS
308 DO 602 J=1,NUNITS
309 DO 602 K=1,NUNITS
310 DO 602 N=1,NUNITS
311 IF (LINK(K,N).EQ.1) THEN

```

```

814 CRITREJ=SIREQ-TOTREJ(I,J,K)
815 IF (CRITREJ.GT.0.AND.TOTREJ(I,J,K).NE.-1) THEN
816     WRITE (OUT,5)
817     WRITE (OUT,43) I,J,K,TOTREJ(I,J,K)
818     FORMAT (' LINK',I2,'-',J2,' TO NODE',I2,'=',I1F8.2,'DB')
819 43
820 *
821 CHECK TO DETERMINE IF CRITICAL LINKS REQUIRE UNIQUE FREQUENCIES
822 *
823 FREQDIF=ABS(FREQ(I,J)-FREQ(N,K))
824 FREQREJ=AA+BB*FREQDIF+CC*FREQDIF**2+DD*FREQDIF**3+
825 EE*FREQDIF**4+FF*FREQDIF**5
826 IF (FREQREJ.GE.SIREQ) THEN
827     WRITE (OUT,1020)
828     FORMAT (" NO PROBLEM")
829 ELSE
830     WRITE (OUT,1030)
831     FORMAT (" PROBLEM")
832     FREQ(I,J)=900.0
833     FREQDIF=ABS(FREQ(I,J)-FREQ(N,K))
834     FREQREJ=AA+BB*FREQDIF+CC*FREQDIF**2+DD*FREQDIF**3+
835     EE*FREQDIF**4+FF*FREQDIF**5
836     IF (FREQREJ.GE.SIREQ) THEN
837         WRITE (OUT,1040)
838         FORMAT (" PROBLEM CORRECTED")
839     END IF
840 END IF
841 END IF
842 END IF
843 CONTINUE
844 602
845 *
846 ASSIGN FREQUENCY CODES TO CRITICAL LINKS
847 *
848 NUMCKIT=0
849 DO 801 I=1,NUNITS
850     DO 803 J=1,NUNITS
851         IF (FREQ(I,J).EQ.900.0) THEN
852             DO 903 N=1,NUNITS

```



```

      +
      IF (FREQ(I,N).EQ.1.OR.FREQ(J,N).EQ.1.OR.
      FREQ(N,I).EQ.1.OR.FREQ(N,J).EQ.1) THEN
        GO TO 111
      END IF
      903 CONTINUE
      FREQ(I,J)=1
      GO TO 666
      111 DO 104 N=1,NUNITS
      IF (FREQ(I,N).EQ.2.OR.FREQ(J,N).EQ.2.OR.
      FREQ(N,I).EQ.2.OR.FREQ(N,J).EQ.2) THEN
        GO TO 222
      END IF
      104 CONTINUE
      FREQ(I,J)=2
      GO TO 666
      222 DO 204 N=1,NUNITS
      IF (FREQ(I,N).EQ.3.OR.FREQ(J,N).EQ.3.OR.
      FREQ(N,I).EQ.3.OR.FREQ(N,J).EQ.3) THEN
        GO TO 333
      END IF
      204 CONTINUE
      FREQ(I,J)=3
      GO TO 666
      333 DO 304 N=1,NUNITS
      IF (FREQ(I,N).EQ.4.OR.FREQ(J,N).EQ.4.OR.
      FREQ(N,I).EQ.4.OR.FREQ(N,J).EQ.4) THEN
        GO TO 555
      END IF
      304 CONTINUE
      FREQ(I,J)=4
      GO TO 666
      555 FREQ(I,J)=5
      666 IF (FREQ(I,J).GT.NUMCKIT) THEN
        NUMCKIT=FREQ(I,J)
      END IF
      803 CONTINUE

```

ASSIGN UNIQUE FREQUENCIES TO CRITICAL LINKS BEGINNING WITH 900.0MHZ
USING 24.0MHZ INTERVALS

```

DO 404 I=1,NUNITS
DO 404 J=1,NUNITS
IF (FREQ(I,J).GT.0.AND.FREQ(I,J).LE.5) THEN
  IF (FREQ(I,J).EQ.1) THEN
    FREQ(I,J)=900.0
  ELSE IF (FREQ(I,J).EQ.2) THEN
    FREQ(I,J)=924.0
  ELSE IF (FREQ(I,J).EQ.3) THEN
    FREQ(I,J)=948.0
  ELSE IF (FREQ(I,J).EQ.4) THEN
    FREQ(I,J)=972.0
  ELSE IF (FREQ(I,J).EQ.5) THEN
    FREQ(I,J)=996.0
  END IF
END IF
404 CONTINUE

DO 1170 CHECK FREQ ASSIGNMENTS FOR PROBLEMS

SUPCRIT=0
IF (NUMCRIT.GT.0) THEN
  WRITE (OUT,5)
  WRITE (OUT,5)
  WRITE (OUT,1170)
  FORMAT (" DOUBLE CHECK FREQ ASSIGNMENTS")
  WRITE (OUT,5)
  WRITE (OUT,5)
  DO 1300 I=1,NUNITS
    DO 1300 J=1,NUNITS
      DO 1300 K=1,NUNITS

```

```

1170 SUPCRIT=0
      IF (NUMCRIT.GT.0) THEN
        WRITE (OUT,5)
        WRITE (OUT,5)
        WRITE (OUT,1170)
        FORMAT (" DOUBLE CHECK FREQUENCY ASSIGNMENTS")
        WRITE (OUT,5)
        WRITE (OUT,5)
        DO 1300 I=1,MUNITS
          DO 1300 J=1,MUNITS
            DO 1300 K=1,MUNITS

```

```

11170      FORMAT (" DOUBLE CHECK FREQUENCY ASSIGNMENTS")
      WRITE (OUT,5)
      WRITE (OUT,5)
      DO 1300 I=1,NUNITS
      DO 1300 J=1,NUNITS
      DO 1300 K=1,NUNITS

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DO 1300 I=1,NUNITS
  DO 1300 J=1,NUNITS
    DO 1300 K=1,NUNITS

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00 1300 K=1,NUNITS

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DO 1300 N=1,NUNITS
  IF (LINK(K,N).EQ.1) THEN
    CRITREJ=SIRED-TOIREJ(I,J,K)
    IF (CRITREJ.GT.0.AND.TOIREJ(I,J,K).NE.-1) THEN
      WRITE (OUT,5)
      WRITE (OUT,1301) I,J,K,TOIREJ(I,J,K)
      FORMAT (' LINK',12,' TO NODE',12,' 11F8.2,
        "DB"')
      +
      1301
      *
      987 *
      988 * CHECK TO DETERMINE IF CRITICAL LINKS REQUIRE UNIQUE FREQUENCIES
      989 *
      990
      FREDDIF=ABS(FREQ(I,J)-FREQ(N,K))
      FREOREJ=AA+BB*FREDDIF+CC*FREDDIF**2+DD*FREDDIF**3+
      EE*FREDDIF**4+FF*FREDDIF**5
      IF (FREOREJ.GE.SIRED) THEN
        WRITE (OUT,1320)
        FORMAT (' NO PROBLEM')
        ELSE
          WRITE (OUT,1330)
          FORMAT (' PROBLEM')
          FREQ(I,J)=1000.0
          WRITE (OUT,1335)
          FORMAT (' 1000.0MHZ ASSIGNED * ')
          FREDDIF=ABS(FREQ(I,J)-FREQ(N,K))
          FREOREJ=AA+BB*FREDDIF+CC*FREDDIF**2+DD*FREDDIF**3+
          EE*FREDDIF**4+FF*FREDDIF**5
          IF (FREOREJ.GE.SIRED) THEN
            WRITE (OUT,1340)
            FORMAT (' PROBLEM CORRECTED ')
            SUPCRIT=SUPCRIT+1
            END IF
          END IF
        END IF
      END IF
    END IF
  END IF
  1013
  1300 CONTINUE
  1014
  END IF
  1015 * PRINT OUT FREQUENCY ASSIGNMENTS CONSIDERING CRITICAL LINKS
  1016
  1017
  1018
  1019

```



```

IF (MAXLINKS.GE.3) THEN
  WRITE (OUT,1080)
  FORMAT ("      810.0MHZ  854.0MHZ")
END IF
IF (MAXLINKS.GE.4) THEN
  WRITE (OUT,1090)
  FORMAT ("      815.0MHZ  859.0MHZ")
END IF
IF (MAXLINKS.EQ.5) THEN
  WRITE (OUT,1100)
  FORMAT ("      820.0MHZ  864.0MHZ")
END IF
IF (NUMCRIT.GE.1) THEN
  WRITE (OUT,1110)
  FORMAT ("      900.0MHZ")
END IF
IF (NUMCRIT.GE.2) THEN
  WRITE (OUT,1120)
  FORMAT ("      924.0MHZ")
END IF
IF (NUMCRIT.GE.3) THEN
  WRITE (OUT,1130)
  FORMAT ("      948.0MHZ")
END IF
IF (NUMCRIT.GE.4) THEN
  WRITE (OUT,1140)
  FORMAT ("      972.0MHZ")
END IF
IF (NUMCRIT.EQ.5) THEN
  WRITE (OUT,1150)
  FORMAT ("      996.0MHZ")
END IF
IF (SUPCRIT.GT.0) THEN
  WRITE (OUT,1155)
  FORMAT ("      1000.0MHZ")
END IF
WRITE (OUT,5)

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VITA

Gregory H. Swanson was born in Heidelberg, Germany on 4 January 1952. He graduated from high school in Kansas City, Missouri in 1970 and attended the University of Missouri-Columbia from which he graduated in May 1974 with a Bachelor of Science degree in Electrical Engineering.

He entered commissioned service in the US Army through ROTC upon graduation from the University of Missouri in 1974. After completing the Signal Officer Basic Course at Ft Gordon, Georgia, he was assigned to Wildflecken, Germany as a Battalion Communications Officer for the 2/15 Infantry Battalion. He completed the Signal Officer Advanced Course upon returning from Germany and was subsequently assigned as a Communications Research and Development Officer for the PATRIOT Project Office at Redstone Arsenal, Alabama in June 1981.

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BLOCK 20: Abstract (Cont'd)

and radio rejection characteristics are incorporated in the model. The model was experimented upon, using deployments currently accepted within the Air Defense Community and the results of the model are analyzed.

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